III.C Power Electronics

III.C.1 Trade Study for Integrating Numerous SECA SOFC Modules

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Objectives

- Identify power topologies that can be used to integrate numerous solid oxide fuel cell modules to supply much higher power than a single module can supply.
- Evaluate the pros and cons of each topology.
- Compare different topologies with respect to each other.

Approach

- Identify the requirements of a power converter for a fuel cell interface.
- Study the electrical supply characteristics of fuel cells.
- Identify power converter topologies with multiple inputs.
- Analyze the possible effects of using several fuel cell modules using multi-input power converters.
- Evaluate the possibility of modifying controls to suit the load by varying voltage output of the fuel cells for better fuel cell utilization.

Accomplishments

- Identified five different families of power converter topologies that can be used to integrate numerous SOFC modules.
- Listed the pros and cons for each power converter topology.
- Developed a level reduction technique applied to multilevel converters integrating several fuel cell modules to increase the fuel cell utilization.
- Built a comparison matrix to compare all these power converter topologies with respect to cost, fault tolerance, reliability, etc.
- Completed the final report.

Future Directions

- Follow the literature for a possible addition to the five power topologies included in this project.
- Examine the possibility of repeating the study for fuel cell hybrid systems.
- Consider conducting a study comparing DC distribution and AC distribution for fuel cell power generation.

Introduction

The U.S. Department of Energy's Solid State Energy Conversion Alliance (SECA) program is targeting solid oxide fuel cell (SOFC) modules in the 3–10 kW range to be made available for residential applications. In addition to residential use, these modules can also be used in apartment buildings, hospitals, etc., where a higher power rating would be required. For example, a hospital might require a 250-kW power supply. To provide this power using the SOFC modules, 25 of the 10-kW modules would be required. These modules can be integrated in different configurations to yield the necessary power. This report will show five different approaches for integrating numerous SOFC modules and will evaluate and compare each one with respect to cost, control complexity, ease of modularity, and fault tolerance.

Approach

The static and dynamic characteristics of SOFCs have been studied to identify the power converter requirements. With these in mind, several multi-input power converter systems have been studied to make sure they will be suitable for integration of numerous SOFCs. Using these converter topologies, the possible effects of integrating several fuel cell modules have been analyzed. Finally, these topologies have been compared with respect to cost, control complexity, reliability, availability (at power system and device levels), fault tolerance, modularity (ability to isolate portions of the system for service or add power generation capacity while other portions of the complete system are still functioning), energy conversion efficiency, and ease of mass customization to enable mass production to drive down costs.

While studying the power converter topologies, it was found that there is a possibility of modifying controls to suit the load by varying voltage output of the fuel cells for better fuel cell utilization. To achieve this, a control technique was developed and analyzed using simulation and some experimentation using batteries instead of fuel cells.

Results

The five power converter topologies selected for integrating numerous fuel cells are series configuration, DC link configuration, high-frequency AC link distribution, cascaded multilevel configuration, and multilevel configuration. A matrix given below compares these configurations with respect to each other.

	A	B	C	D	E
a	1	3	3	3	5
b	1	4	4	4	5
c	4	2	2	2	3
d	1	1	1	1	5
e	5	1	1	1	1
f	5	1	2	2	2
g	1	3	3	2	4
h	1	2	2	2	2

A. Series configuration

B. Cascaded multilevel configuration

C. Multilevel configuration

D. DC link configuration

E. High-frequency AC (hfac) link configuration

a. Cost (capital and operating) (1-Less expensive, 5-More expensive)

b. Control complexity (1-Less complex, 5-More complex)

c. Reliability (1-More reliable, 5-Less reliable)

d. Availability (at power system and device levels) (1-Better availability, 5-Worse availability)

e. Fault tolerance (1-More fault tolerant, 5-Less fault tolerant)

f. Modularity (ability to isolate portions of system for service or add power generation capacity while other portions of the complete system are still functioning) (1-More modular, 5-Less modular)

g. Energy conversion efficiency (1-More efficient, 5-Less efficient)

h. Ease of mass customization to enable mass production to drive down costs (1-Easier, 5-More difficult

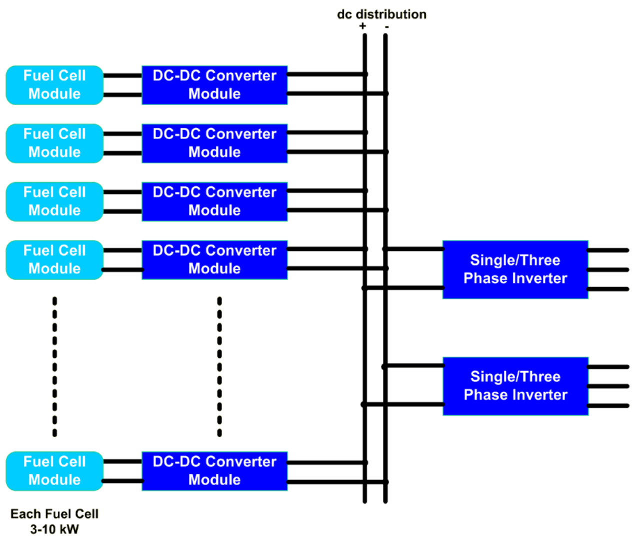

Figure 1. Block Diagram of the DC Distribution Configuration

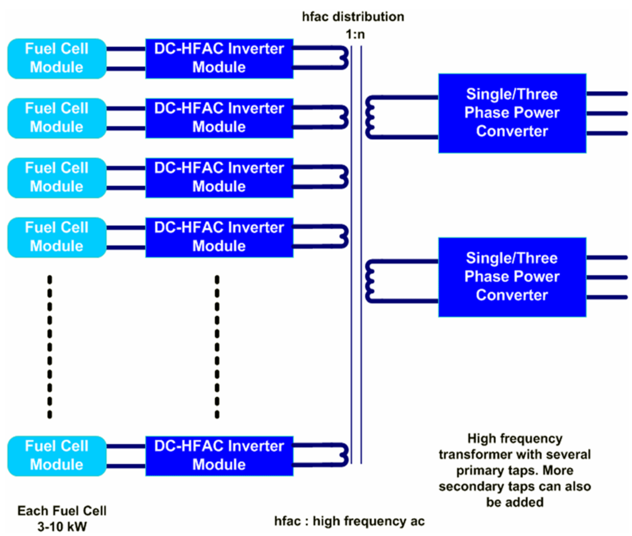

Figure 2. Block Diagram of the hfac Distribution Configuration

Figures 1 and 2 show the block diagrams of the DC link configuration and the hfac link distribution configuration, respectively.

The output voltages of fuel cells vary with load current. The power converter does not always operate at full load at rated fuel cell voltage. As the load current decreases, the fuel cell output voltage increases. This causes challenges in the converter design, since the converter switches have to be derated to accommodate the higher voltages. When numerous fuel cell modules are integrated, as the

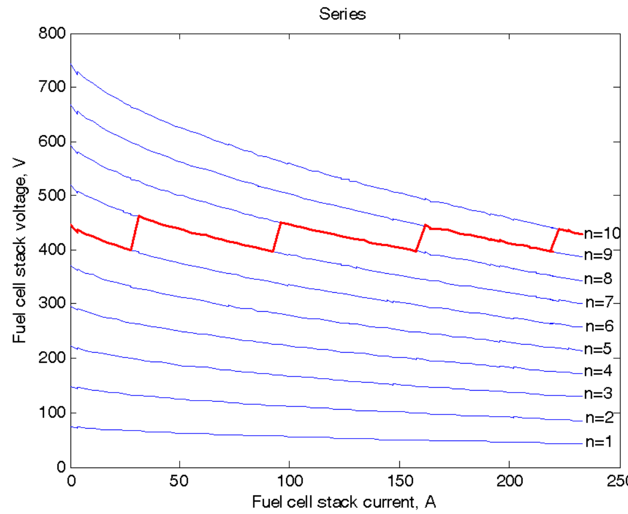

Figure 3. Static Characteristics for up to 10 Fuel Cells in Series and Level Reduction Technique

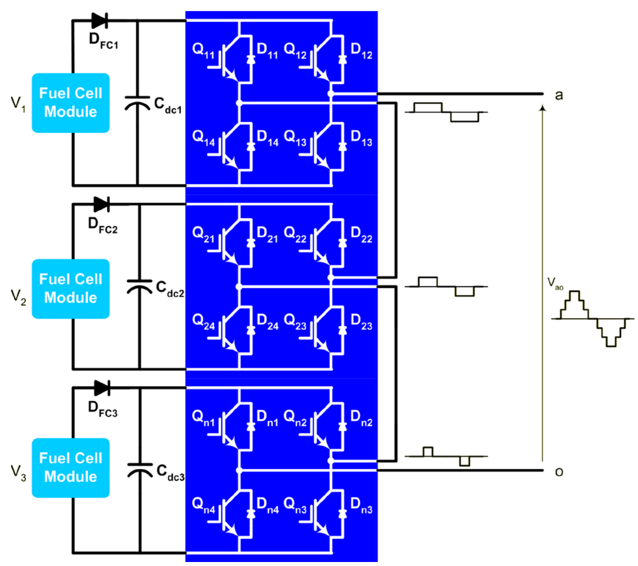

Figure 4. One Phase of a Cascaded Three-Level Inverter

load current decreases, some number of fuel cells can be taken off-line so that the remaining fuel cells can still provide the same power but at a voltage close to the rated value. This is called the level reduction control technique. A cascaded multilevel DC-DC converter is the best choice for this operation. Figure 3 shows the static characteristics of 1 to 10 fuel cells in series and how the level reduction works as the current decreases. As seen in this figure, even though fewer fuel cells are used, they can still supply the required power. Since level reduction technique keeps the fuel cell output voltage lower, lower voltage rated devices can be used in the converters.

Figure 4 shows a cascaded multilevel inverter, which can also be controlled with the level reduction technique. In this case, the inverter switches are turned on and off by a fundamental frequency sine-triangle comparison technique developed for this converter which reduces the inverter levels (or takes fuel cells off-line) automatically, when needed.

Conclusions

Novel multiple-input converter topologies for fuel cells have been reviewed and compared with each other.

With level reduction control technique exploiting the V-I characteristics of fuel cells, the need for derating power semiconductors in fuel cell systems is eliminated. By inhibiting some of the fuel cells and using the inhibited fuel cells in other applications, like charging batteries, the system efficiency and the fuel cell utilization increase. If these fuel cells are left idling, then the life expectancy of the system increases. In addition to these benefits, using a multilevel converter also brings the advantages of modularity and increased reliability.

For the multilevel inverter, a fundamental switching sine-triangle comparison method is introduced. This method decreases the complexity of the level reduction control for the multilevel inverters by eliminating the need for storing separate switching angle look-up tables for each number of DC sources.

The level reduction technique is also applicable to other fuel cell-fed multilevel inverters.

FY 2005 Publications/Presentations

1. B. Ozpineci, D. J. Adams, and L. M. Tolbert, Trade study on aggregation of multiple 10-kw solid oxide fuel cell power modules, Report ORNL/TM-2004/28, November 2004.